RETROSPECTIVE

Mildred S. Dresselhaus (1930–2017): A fierce force of harmony

Nai-Chang Yeh[a,1]

Prof. Mildred S. Dresselhaus, fondly known as "Millie" and "Queen of Carbon Science," passed away at age 86 on February 20, 2017. She was a pioneer in the research of carbon nanomaterials, a giant in experimental condensed matter physics, a fine musician, a compassionate mentor and role model to young people, a strong advocate for women in science and engineering, and a selfless and impactful citizen of the scientific community.

I still remember my first meeting with Millie in September of 1983. I was a first-year Massachusetts Institute of Technology graduate student, newly arrived in the United States from Taiwan. Having never left Taiwan while Taiwan was still under the martial law before my journey to Boston, I was understandably anxious about what may lie ahead in a completely strange environment. Nonetheless, Millie was able to make me feel at ease and welcome almost instantaneously with her trademark brilliant smile when we met. Since then, I have had the good fortune of becoming one of her doctoral students.

Millie Dresselhaus and Nai-Chang Yeh at the Kavli Foundation reception during the 2016 Kavli Prize Week in Oslo, Norway.

As an advisor, Millie was always supportive but also allowed her students sufficient freedom to develop their own research direction and independence. She held weekly group meetings and met with students to discuss research regularly, despite her busy schedule and many commitments. Millie was amazingly patient when interacting with students, and she placed strong emphasis on training students' communication skills so that they could deliver ideas and research results with rigor, clarity, and efficiency. She generously supported her group members attending multiple conferences per year to ensure that they could broaden their horizon and receive proper exposure to the research community. In addition to being a fine academic mentor, Millie was compassionate and generous. Every Thanksgiving Millie would host and personally prepare a wonderful dinner for her group members in her house. The feast would be followed by a nice chamber music concert, where Millie played the violin together with her family of string musicians.

I completed my doctoral thesis on the electronic and magnetic properties of various types of graphene intercalation compounds in January of 1988, and with Millie's recommendation I was able to start my postdoctoral research on high-temperature superconductivity at IBM's, Watson Research Center in New York. In 1989 I joined the physics faculty at the California Institute of Technology, where Millie became a trustee shortly afterward. She visited me often when she came to Pasadena for the Board of Trustees meetings. Millie would show up with bags full of papers that she had been diligently working on while she was traveling, such as draft chapters of her group theory book, manuscripts she was reviewing for scientific journals, draft reports she was writing for various committee duties, and letters of recommendation for her students. When we met, Millie was always encouraging and interested in my research, asked good questions, and was also spirited in describing her own work.

Millie made many important contributions to the research fields of graphite, graphite intercalation compounds, carbon fibers, fullerenes, carbon nanotubes, graphene, and thermoelectric effects of low-dimensional and nanoscale structures. Among her various "firsts": Millie theoretically predicted and then experimentally

[a]Department of Physics, California Institute of Technology, Pasadena, CA 91125

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[1]Email: ncyeh@caltech.edu.

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verified with Raman spectroscopy that single-wall carbon nanotubes could be either semiconducting or metallic, depending the chiral vector of the nanotube (1). She also pioneered the theoretical notions and then provided experimental proof-of-principle verifications of using quantum-well superlattice structures and quantum-wire samples to significantly improve the thermoelectric figure of merit of materials (2, 3). These ideas stimulated subsequent advances in the employment of nanoscale constituents to further enhance the thermoelectric figure of merit (4).

Millie won many distinguished professional honors and awards, including the Institute of Electrical and Electronics Engineers Medal of Honor (2015), the Presidential Medal of Freedom (2014), the Von Hippel Award, Materials Research Society (2013), the Kavli Prize in Nanoscience (2012), the Enrico Fermi Award (2012), the Oliver E. Buckley Condensed Matter Prize, American Physical Society (2008), the Oersted Medal (2007), L'Oréal-United Nations Educational, Scientific, and Cultural Organization Awards for Women in Science (2007), the Dwight Nicholson Medal for Outreach, American Physical Society (1999), and the National Medal of Science (1990). She also received many honorary degrees, and was an elected member of the National Academy of Engineering, National Academy of Sciences, and the American Philosophical Society. Millie advised more than 75 doctoral students in her career, including about 20% women and a significant number of African Americans. According to the Web of Science on May 3, 2017, Millie had published 1,205 papers, received 82,983 citations (excluding self-citations), and reached an h-index of 133 (https://webofknowledge.com). Among many important services to the scientific community, Millie was President of the American Physical Society in 1984, Treasurer of the National Academy of Sciences from 1992 to 1996, President of the American Association for the Advancement of Science in 1997, and Director of the Office of Science at the US Department of Energy from 2000 to 2001.

In addition to her breathtaking accomplishments in physics, education, and scientific services, an attribute of Millie that made her stand out among many scholars was the harmony with which she conducted herself, no matter what the circumstances may be. Millie had the unique ability to handle all challenges with calm, wisdom, fairness, and firmness. Perhaps it had something to do with the musician in her. Music was an important part of Millie's life since her childhood, and she kept up playing classical music regularly until age 86, typically twice a week in the evenings at home with friends. Prof. Patrick Lee, her colleague at the Massachusetts Institute of Technology and one of her chamber music friends, recalled how skillful Millie was as a violinist and how kind and patient she was in guiding less-experienced players.

Millie was a fierce force of harmony in all aspects of her life. Her legacy will live on through her work, her services, and all of the souls she generously touched.

The directors and codirectors of various Kavli Nanoscience Institutes spontaneously gathered around Prof. Millie Dresselhaus at Oslo City Hall during the Kavli Prize Banquet on September 6, 2016. From left to right: Profs. Lieven Vandersypen (Delft University), Nai–Chang Yeh (California Institute of Technology), Cees Dekker (Delft University), Millie Dresselhaus (Massachusetts Institute of Technology), Paul Alivisatos (University of California, Berkeley), and David Muller (Cornell University).

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2 Hicks LD, Dresselhaus MS (1993) Effect of quantum-well structures on the thermoelectric figure of merit. *Phys Rev B Condens Matter* 47:12727–12731.

3 Hicks LD, Dresselhaus MS (1993) Thermoelectric figure of merit of a one-dimensional conductor. *Phys Rev B Condens Matter* 47:16631–16634.

4 Dresselhaus MS, et al. (2007) New directions for low-dimensional thermoelectric materials. *Adv Mater* 19:1043–1053.